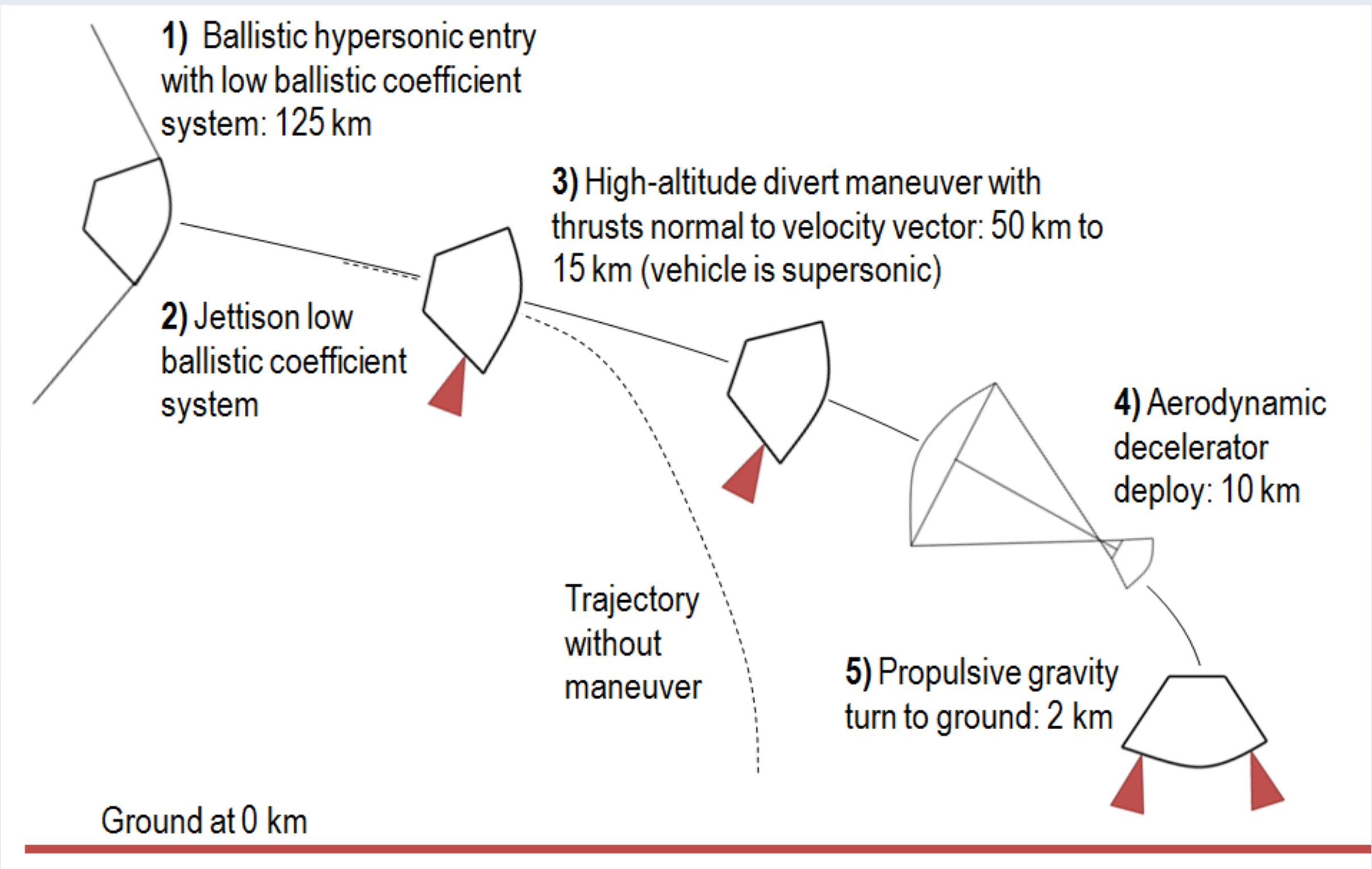


Introduction

Future Mars missions seek to increase landed mass and accuracy

- Increasing landed mass can be accomplished with low ballistic coefficient (low- β) hypersonic vehicles and supersonic retropropulsion (SRP)
- Past efforts have tended to focus precision landing efforts on hypersonic and propulsive terminal descent guidance
 - May be physically difficult to implement a guided hypersonic entry system on a large low- β vehicle
 - Large propulsive diverts performed solely in the terminal phase of flight require considerable propellant and reduce payload mass
- **It is postulated that decoupling the divert maneuver from a traditional propulsive terminal descent maneuver reduces the propellant required to achieve precision landings.**
- Low- β vehicles decelerate higher in the atmosphere, possibly allowing for more timeline and altitude to perform such a divert maneuver.
- This study will assess the propellant mass required and accuracy of an architecture utilizing a low- β vehicle and a divert maneuver.

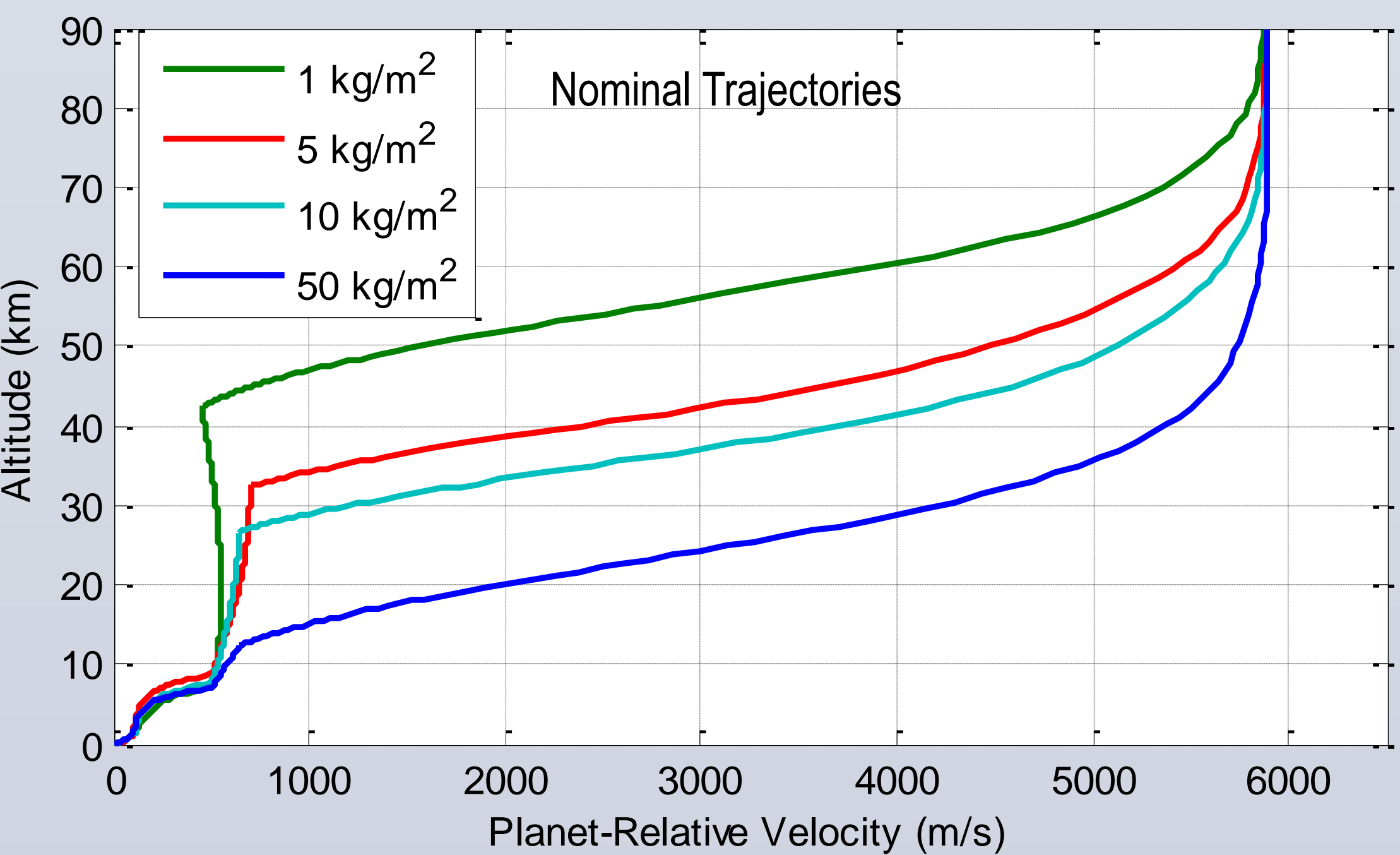
Architecture Description



Reference Mission

A Mars Science Laboratory (MSL) vehicle with a mass of 3300 kg will be simulated:

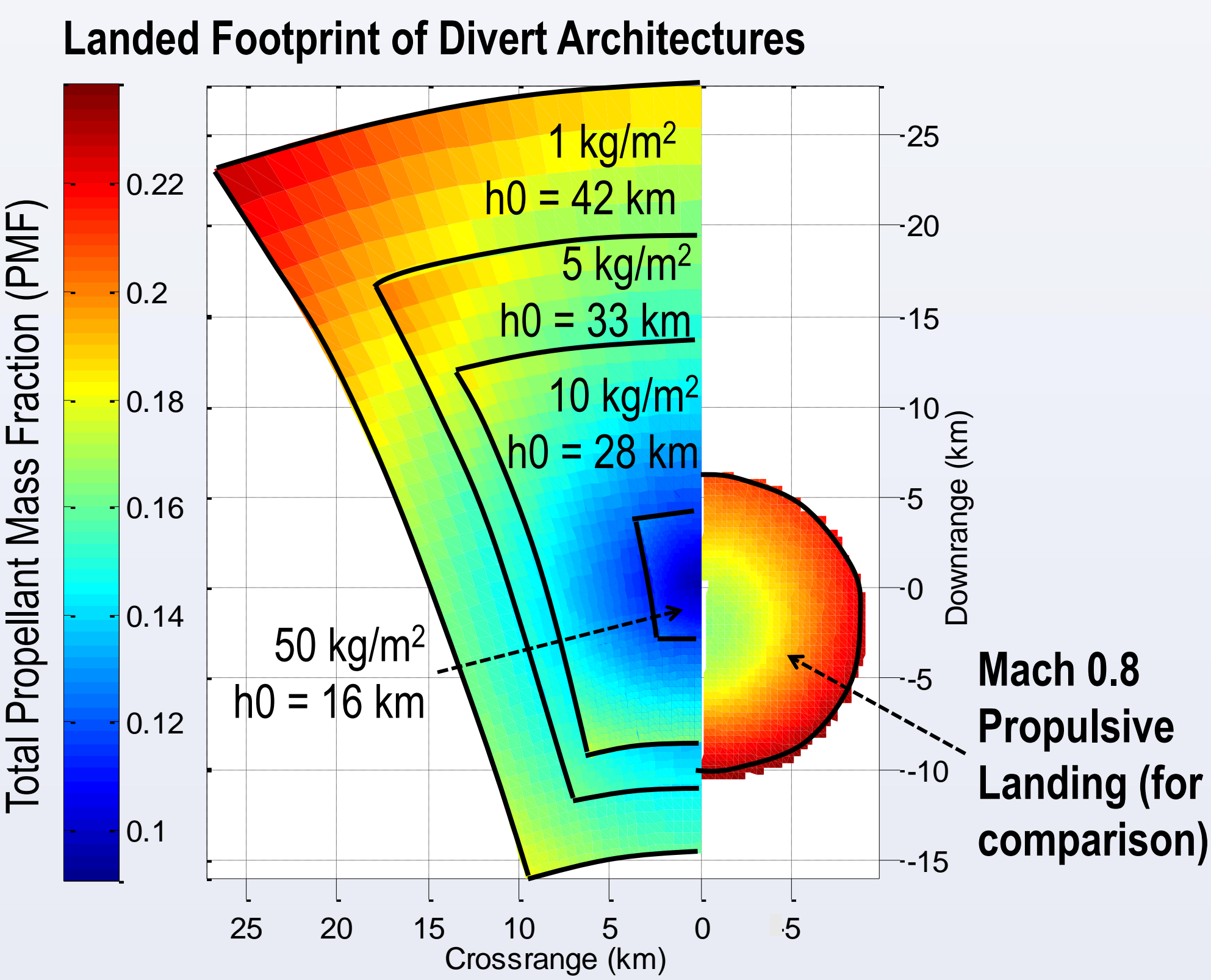
Architecture Flight Regime	Approach
Ballistic entry: $V_{125\text{ km}} = 6.1\text{ km/s}$ and $\gamma_{125\text{ km}} = -15.5^\circ$	70° sphere-cone with increased diameter to decrease ballistic coefficient
High-altitude divert maneuver	4 x 2 Mars Landing Engines (MLEs, Thrust = 3100 N) spread equally around vehicle
Aerodynamic decelerator	19.7 m Disk-Gap-Band parachute (MSL)
Propulsive gravity turn	8 MLEs (MSL)



Acknowledgments

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Nominal Results - Divert Performance

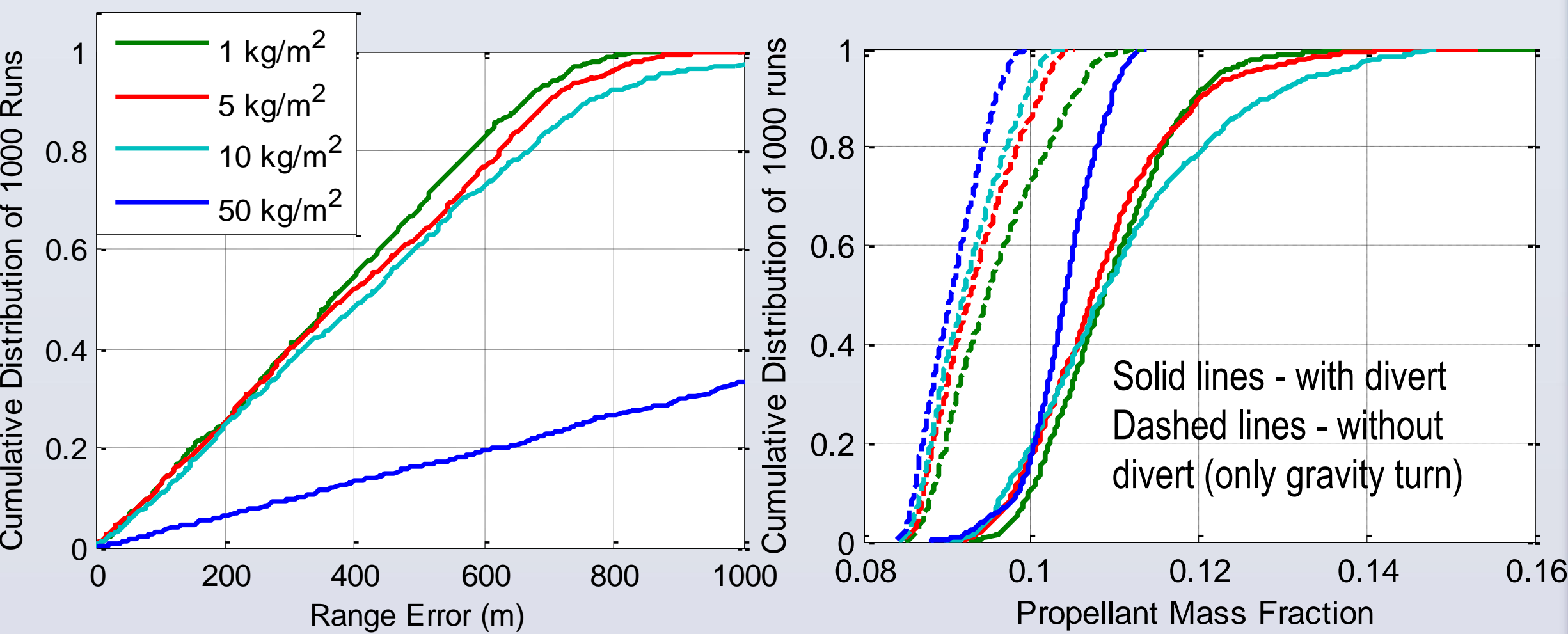


Note: Range footprints are symmetric about the crossrange = 0 km axis. Propellant mass fraction is defined as the mass of propellant for both the divert and propulsive gravity turn over the total entry mass

- This architecture was compared to one where instead of the divert, an optimal terminal descent initiated at Mach 0.8 to the target (same footprint for all β 's)
- As β decreases, time for the maneuver increases, and greater range is achieved
- Propellant mass fractions are reduced by 25% compared to the traditional architectures

Dispersed Performance

1000 Monte Carlo runs, with relevant dispersions on the entry state, atmosphere/winds, mass, and aerodynamics, were used to assess the performance of the architecture



For $\beta \leq 10\text{ kg/m}^2$, landed range error under 1 km can be achieved. The primary sources of range error are parachute drag uncertainty and winds. The propellant mass fraction required for these diverts is at most 5% greater than for cases that do not use a divert (only gravity turn).

System-Level Consideration: Payload Mass Trade

Payload Mass Trade	Mass contribution of precision landing system	Other considerations
MSL Style Architecture	18% of total entry mass (300 kg ballast for lifting entry, 300+ kg propellant for landing)	RCS and necessary prop. add mass (may be worse for large low- β vehicles)
High-Altitude Divert Architecture	15% of total entry mass (prop. needed for divert maneuver and gravity turn at 99 th %-tile)	Additional large engines and prop. tanks add mass

Conclusions and Future Work

- The EDL architecture proposed here has shown potential as one that can enable precision landing for vehicles on Mars without the use of guided entry.
- For entry systems with $\beta \leq 10\text{ kg/m}^2$, landed accuracies up to 1 km can be attained, for a total propellant mass fraction of 15%, only 5% more than needed without the divert.
- Future work will involve studies of different mission types, including ones with guided entry and SRP. The SRP mission type is of interest, as it already is a propulsion-intensive architecture. Further system considerations, such as thruster size, range and PMF sensitivities to initial conditions, and configuration options will be assessed, with a focus on mission design.